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TELEMETRY LINK FOR  
AN AUTOMATIC SALMON MIGRATION MONITOR

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by

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For

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INTRODUCTION

The antenna and transmitter described in this report were designed for integration into the remote acoustic assessment system for detection of sockeye salmon in the Bristol Bay region of the Bering Sea. This system is described in a report prepared by the Applied Physics Laboratory and the Fisheries Institute of the University of Washington, November 1972.

A sketch of the assessment system configuration is shown in Figure 1. It consists of an upward directed sonar buoy anchored 150 feet below the surface and attached by cable to a spar buoy tethered some 300 feet laterally. The spar buoy contains a telemetry transmitter, power supply, data processing electronics, an antenna and a beacon light.

Previous experience with telemetry from small floats and buoys, especially in tracking marine turtles,<sup>(1)</sup> has led to some understanding of the

practical problems of transmitting data under these conditions. An antenna on a small platform in moderate seas is very seldom tuned or matched because of the variable spacing between the active region of the antenna and the sea water surface. We have given considerable thought to the buoy antenna design in this report in the hope of arriving at a useful design compromise for the small buoy problem.

#### GROUND WAVE TRANSMISSION

The presence of the sea, a good conductive surface, modifies propagation at low and high frequencies by refraction. We have selected a frequency of 8 MHz based on prior experience. Figure 2 is a prediction of signal strength at various ranges to 100 miles for radiated power levels of 1 and 10 watts. These curves are based on calculations given by Terman<sup>(2)</sup> and include spherical spreading, diffraction and refraction effects. We would expect signal strengths of 58 dB at 20 miles and 45 dB above 1 microvolt per meter at 70 miles using 10 watts of radiated power. These ranges are those assumed for the transmission path lengths of interest. These calculations are based on the assumption that both

the receiving and transmitting antennas will be located at or near the sea surface.

#### SKY WAVE PROPAGATION

Ranges less than several hundred miles are not suitable for sky wave propagation via the ionosphere at 8 MHz. The major effect of skywave propagation is to increase the noise level at sunrise and sunset as the ionospheric ionization levels enhance reception from distant stations. Final frequency selection around 8 MHz should be made after a field survey of the reception characteristics at the receiver site. A directive antenna for the receiver should help in the reduction of noise.

#### NOISE LEVELS ANTICIPATED

The major noise sources other than man-made interference at 8 MHz expected in the Bristol Bay region are atmospheric and galactic. A directive receiving antenna should be of some benefit in the reduction of all three noise sources.

The equation

$$E_n = F_a + 20 \log F - 65.5 \quad (3)$$

gives the rms noise field for a 1 kHz bandwidth in dB above 1 uv/m for values of  $F_a$ , the atmospheric

noise level in dB above KTB, and frequency in megahertz.  $F_a$  values are provided for various seasons, time of day and localities by CCIR Report 322.<sup>(4)</sup> Using a value of 20 dB for  $F_a$  and 6 kHz for bandwidth,

$$E_n = 12 \text{ dB below } 1 \text{ uv/m}$$

The equation for  $E_n$  is derived from measurements made with a short vertical antenna.

#### SIGNAL TO NOISE RATIO

With the following assumptions:

- transmitter power 10 watts
- transmitter antenna efficiency 50%
- receiver antenna gain 0 dB
- receiver bandwidth 6 kHz
- distance 70 miles
- fade margin 10 dB

the signal to noise ratio should be at least 44 dB.

Reduction of the transmitted power to 1 watt would still provide more than adequate signal to noise ratio under these assumptions and this has in fact been our experience in temperate and tropic zones. For this study, 1 watt of power to the transmitter antenna would provide a field strength of at least 35 uv/m at the receiving antenna.

### BUOY ANTENNA

The following specifications were established for the buoy antenna:

1. Transmitted signal to be vertically polarized.
2. Total antenna height should not exceed 3 feet, to limit wind and wave loading in storm conditions.
3. The antenna must accept 10 watts average power at 8.0 MHz.
4. The maximum diameter ground plane at the top of the spar buoy is approximately 24 inches.
5. The antenna efficiency should be as high as practical within the above physical constraints.

### ANTENNA CONFIGURATIONS CONSIDERED

The following antennas were studied to determine feasibility:

1.  $\lambda/4$  whip
2. 3-foot vertical antenna, base loaded
3. 3-foot vertical antenna, center loaded
4. 3-foot vertical antenna, top loaded
5. DDRR<sup>(5)</sup> antenna with a 6-inch vertical section and spiral top section
6. 3-foot THC (Top Horizontal Coil: 3-foot vertical section with horizontal solenoid top)
7. 2-foot THC (2-foot vertical section with identical solenoid to that of 6)

An 8-foot uniformly loaded vertical whip was also constructed for use as the standard comparison antenna

in field measurements, but was not included in the analysis because of the excessively large ground plane required.

#### RADIATION RESISTANCE AND LOSS RESISTANCE

If the impedance of a vertical antenna is measured at the base with a vector impedance meter, the impedance of a resonant antenna will be found to be purely resistive--a value we will call  $R_b$ . For the sake of this discussion, we will assume quadrature components due to dielectric losses to be negligible. The base resistance  $R_b$  will consist of the radiation loss,  $R_T$  and the heat loss due to the finite conductance of the antenna,  $R_L$ .

For an infinitesimal antenna the power into the base is

$$W = I_o^2 R_b = I_o^2 (R_T + R_L)$$

Where

$I_o$  = average rf current into base of antenna

$R_T$  = total radiation loss

$R_L$  = total ohmic heat loss

The above statement is correct only if all radiation and ohmic losses are subject to current  $I_o$ . In reality, the current in an antenna varies as  $I_o \cos \theta$

where  $\theta = 0^\circ$  at the base, and  $90^\circ$  at the top of the antenna if the system is resonant.

Each antenna is calculated in piece-wise fashion to determine contribution to the horizontal radiation resistance ( $R_H$ ), the vertical radiation resistance ( $R_V$ ) and loss resistance  $R_L$ . Where coil loading is used, only the loss resistance in the loading coil is used for  $R_L$  because in practical cases this is usually 99% of the loss.

For comparison of antennas, the ground loss is assumed to be zero. Obviously during agitated sea states the quarter wave whip would not be usable and the effect of sea spray would affect all antennas. The effect of the sea spray is impossible to rigorously calculate, but we assume all three models would be enclosed in a fiberglass shell or radome filled with dielectric low-loss foam.



TABLE 1.

Summary of Antenna Calculations

	<u>Radiation</u>	<u>R</u>	<u>Loss</u>	<u>Efficiency %</u>	
				<u>Vertically Polarized</u>	<u>Horizontally Polarized</u>
Antenna	$R_V$	$R_H$	$R_L$	$N_V$ $N_H$	
$\lambda/4$ whip (30.76 ft)	38	0	0.1	99.7	0
3-ft base loaded	.94	0	1.2	0.7	0
3-ft center loaded	.94	0	1.5	42.7	0
3-ft top loaded	.94	0	2.6	42.25	0
DDRR	.028	0	2.8	2	0
3-ft Top H Coil	.94	.94	.38	59	29
2-ft Top H Coil	.43	.94	.38	39.5	43

ANTENNA CALCULATIONS

The efficiency of an antenna, for the purposes of this study, is the ratio of total useful radiated power to the total power delivered to the antenna.

$$\text{Efficiency} = \frac{W_V + W_H}{W_V + W_H + W_L}$$

where

$W_V$  = watts radiated, vertically polarized

$W_H$  = watts radiated, horizontally polarized

$W_L$  = total loss resistance

In these calculations we regard all radiated power as "useful" and antennas are assumed to be impedance matched to the radio frequency source.

Radiation resistance for vertical antennas of various electrical lengths are plotted in Figure 3. This curve is derived from equation 22, page 793 of Terman.<sup>(2)</sup> An approximation to the equation for the linear portion of the curve is given by

$$R_V = 1578 \left(\frac{H}{\lambda}\right)^2$$

For 8 MHz a quarter wave antenna would have a radiation resistance,  $R_V \cong 38$  ohms.

To compare various antennas we have assumed a base current of  $I_0 = A \cos \theta$  where  $A = 1$ . The average current in a quarter wave section would be .707. In this case the power radiated would be

$$W_R = (R_V + R_H) I_{ave}^2 = 18.99 \text{ watts}$$

Assuming a loss resistance of 0.1 ohms

$$W_L = R_L I_{ave}^2 = 0.05 \text{ watts}$$

The efficiency is 99.7%

The calculations of Table 1 are based on similar assumptions for each type of antenna.

#### FIELD MEASUREMENTS

After calculating the vertical and horizontal efficiencies, full scale electrical models were constructed of the DDRR, the 2-foot top horizontal coil, and the 3-foot top horizontal coil loaded antennas. A vertical whip was used as a reference antenna.

All antennas were connected to a ground plane consisting of eight each #12 radials 20.76 feet long. All antennas were adjusted for match to 50 ohm coax with a Hewlett-Packard vector impedance meter. A battery operated signal generator was used to drive the antennas to eliminate AC lines in the vicinity of the test antennas.

For the receiving antennas an 8 MHz horizontal dipole and a quarter wave vertical dipole were used with a precision attenuator between the antenna and a GPR-90 receiver. The GPR-90 was operated at constant input. Calibration runs utilizing the standard vertical dipole on the transmitting end were made before and after each experimental measurement.

#### COMPARISON OF TEST ANTENNAS

	<u>Vertical</u>	<u>Horizontal</u>
Vertical Cal Antenna (8')	+14 dB	0 dB
3-foot THC	+17.5 dB	+23 to +26 dB
2-foot THC	+15 dB	+20 dB
6-inch DDRR	0 dB	0 dB

From the above data the 3-foot THC is 2.5 dB better than the 2-foot THC for vertical polarization 3 to 6 dB superior for horizontal polarization.

For tilt angles of  $45^\circ$  the 3-foot THC signal decreases 5 dB and for  $60^\circ$  tilt 7 dB.

Since the horizontal coil section is a semicircle (but not over  $180^\circ$ ), the horizontal pattern on the 3-foot THC is within 3 dB of an omnidirectional radiator and contributes significantly to vertical radiation under tilt conditions.

Foreshortening antennas results in limited bandwidth. The antennas tested were measured on a Hewlett-Packard Vector Impedance Meter to insure adequate bandwidth for this application. The Smith Chart for the 3-foot THC is shown in Figure 4.

The DDDR antenna mathematics collapse for structures with a high vertical section in comparison with the base diameter. The characteristic impedance of the top section becomes excessive and the antenna degenerates into a capacity loaded vertical.

#### TELEMETRY TRANSMITTER DESIGN

##### Summary of Specifications

Range: nominal 20 to 70 miles, 100 miles maximum

Data Transmission: up to 100 bites

Bit Rate: 1 kHz

(cont.....)

Summary of Specifications (Cont.)

Data Transmitted: Fish count  
Distribution data  
Synchronization Code  
Buoy identification

Frequency: 8 MHz

Transmitter power output: 10 watts

Modulation: FSK - 2375 Hz mark  
3500 Hz space

MODULATION

In the FSK or AFSK mode of operation the carrier is on continuously, but the carrier frequency or sideband is shifted to represent a space or mark.

The FCC regulation will permit any frequency shift up to 900 Hz. The circuitry shown on APL University of Washington drawing 29787 indicates frequencies of 3500 and 2375 Hz for a shift of 1125 Hz and audio-shift keying (A2 transmission). Nominally for operation below 50 MHz FCC regulation allows only F1 or FSK to be used.

The transmitter design conforms to the APL University of Washington report; however, special authorization may be required from the FCC for this mode of operation.

### TRANSMITTER DESIGN

A block diagram of the telemetry transmitter is shown in Figure 4. The transmitter consists of an all solid state design beginning with a fundamental frequency crystal oscillator on 8 MHz driving three rf amplifier stages. The final rf amplifier stage uses a 2N5070 transistor capable of a conservative 10 watts output with high level modulation.

The modulator consists of an LM380 integrated circuit driving a Motorola MJE3055 transistor. APL drawing 29774 shows an 18 volt battery supply gated by a 2N3767 transistor for data transmission. The circuit is compatible with this arrangement.

### CONCLUSION

This report outlines a telemetry data link design for use with the tethered automatic fish counter described by the Applied Physics Laboratory, University of Washington. For a small buoy in various sea conditions, we recommend a short vertical antenna with a horizontal semicircular loading coil to operate at a frequency of 8 MHz. A transmitter design is provided which will produce a nominal 10 watts of radio frequency power and be capable of frequency shift keying.

COMMENT ON 3-FOOT TOP HORIZONTAL COIL ANTENNA  
TAPPED AT 1 3/4 TURNS:

This impedance plot indicates the tap point is at too high an impedance point on the coil, resulting in dual resonances at 7.96 and 7.996 MHz and a restricted range over which the antenna will provide a VSWR of 2 or less to the transmitter.

When proper tap point is used (as shown in the impedance plot for L turn), the antenna is resonated with the BFC-12 capacitor. The tap point is relatively broad with respect to the frequency of resonance, but the BFC-12 is very sharp.

For a given tap point the shape of the impedance plot remains identical, but tuning the capacitor rotates the position of any given frequency on the curve.

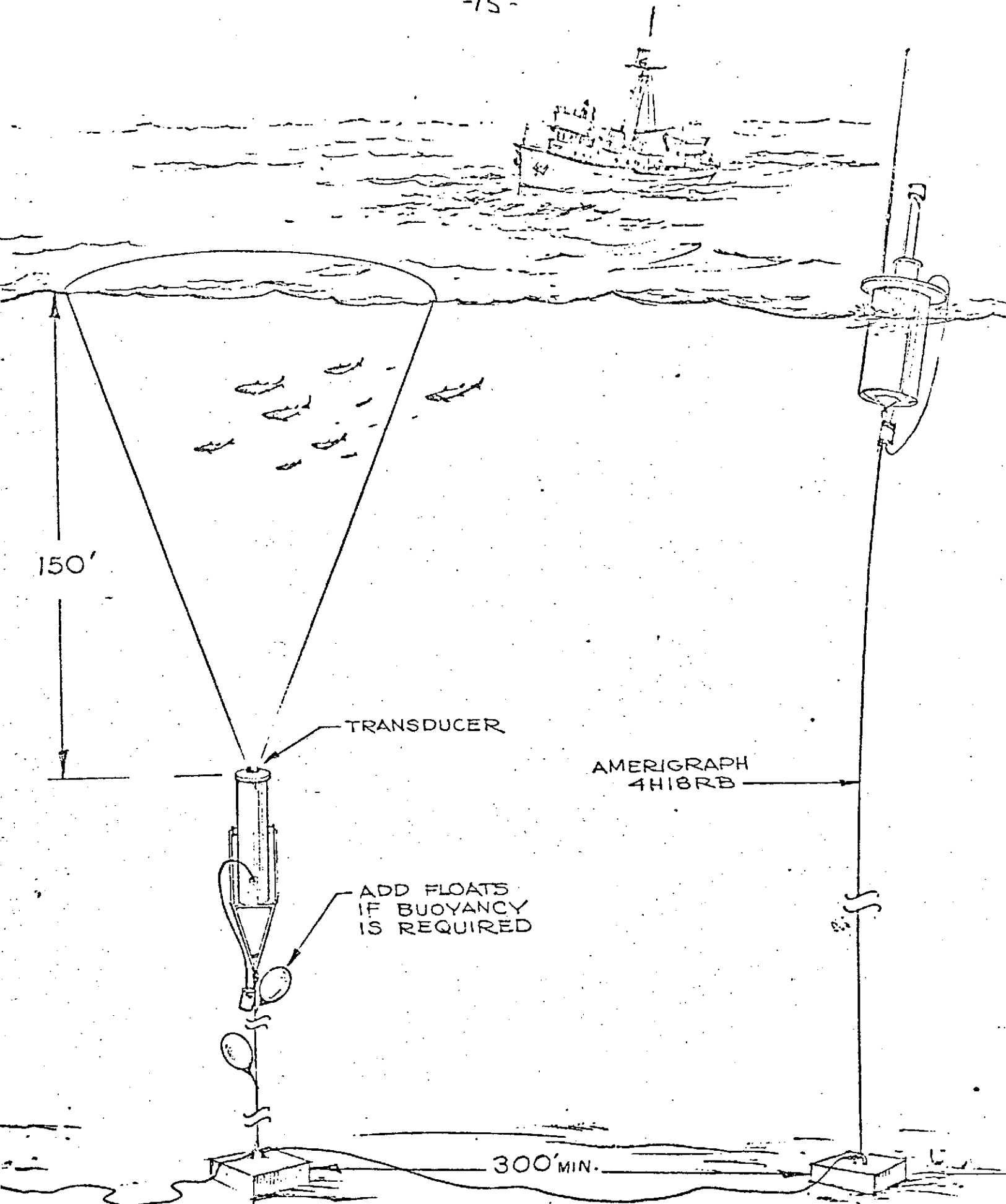
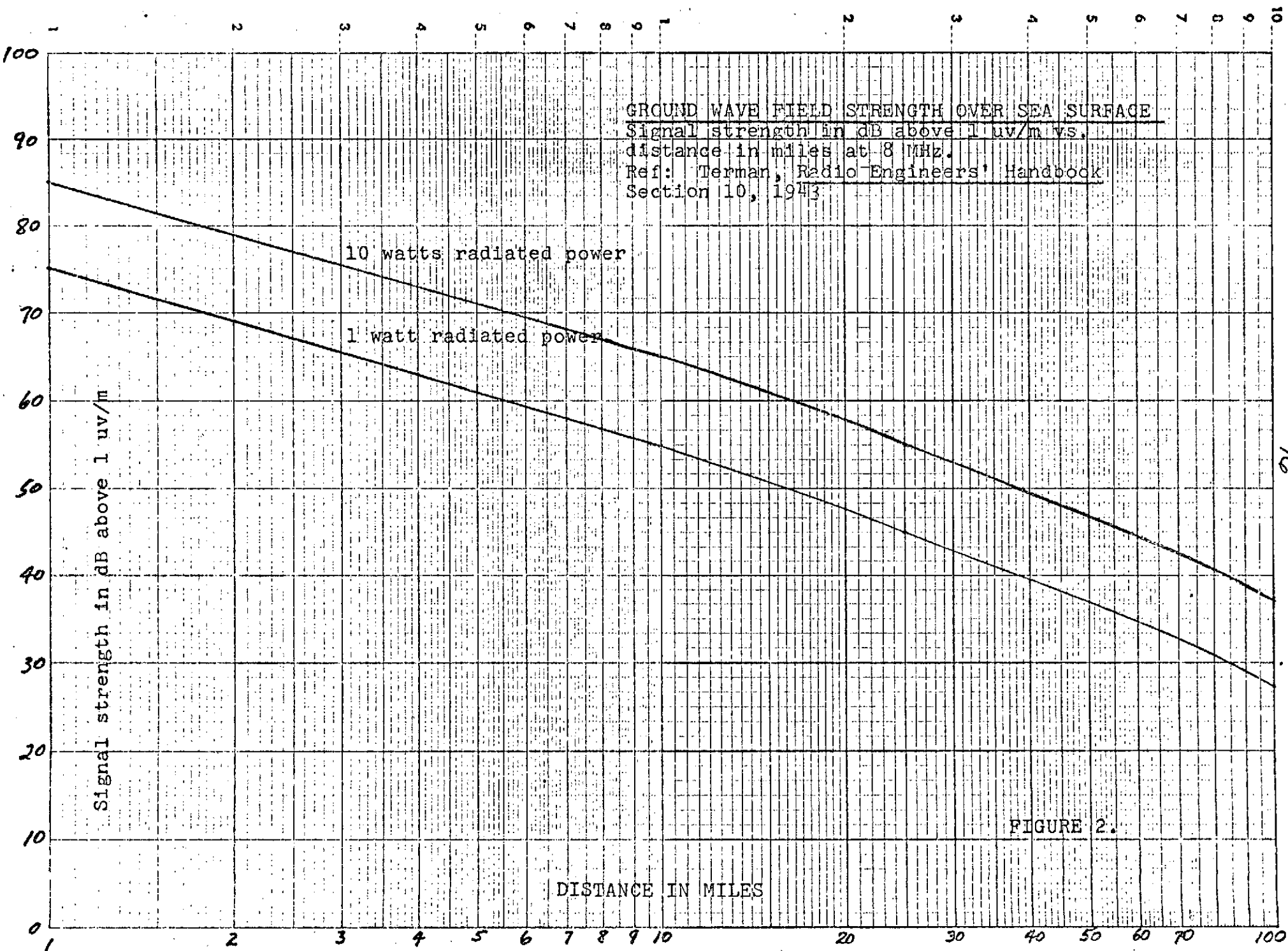


FIGURE 1.





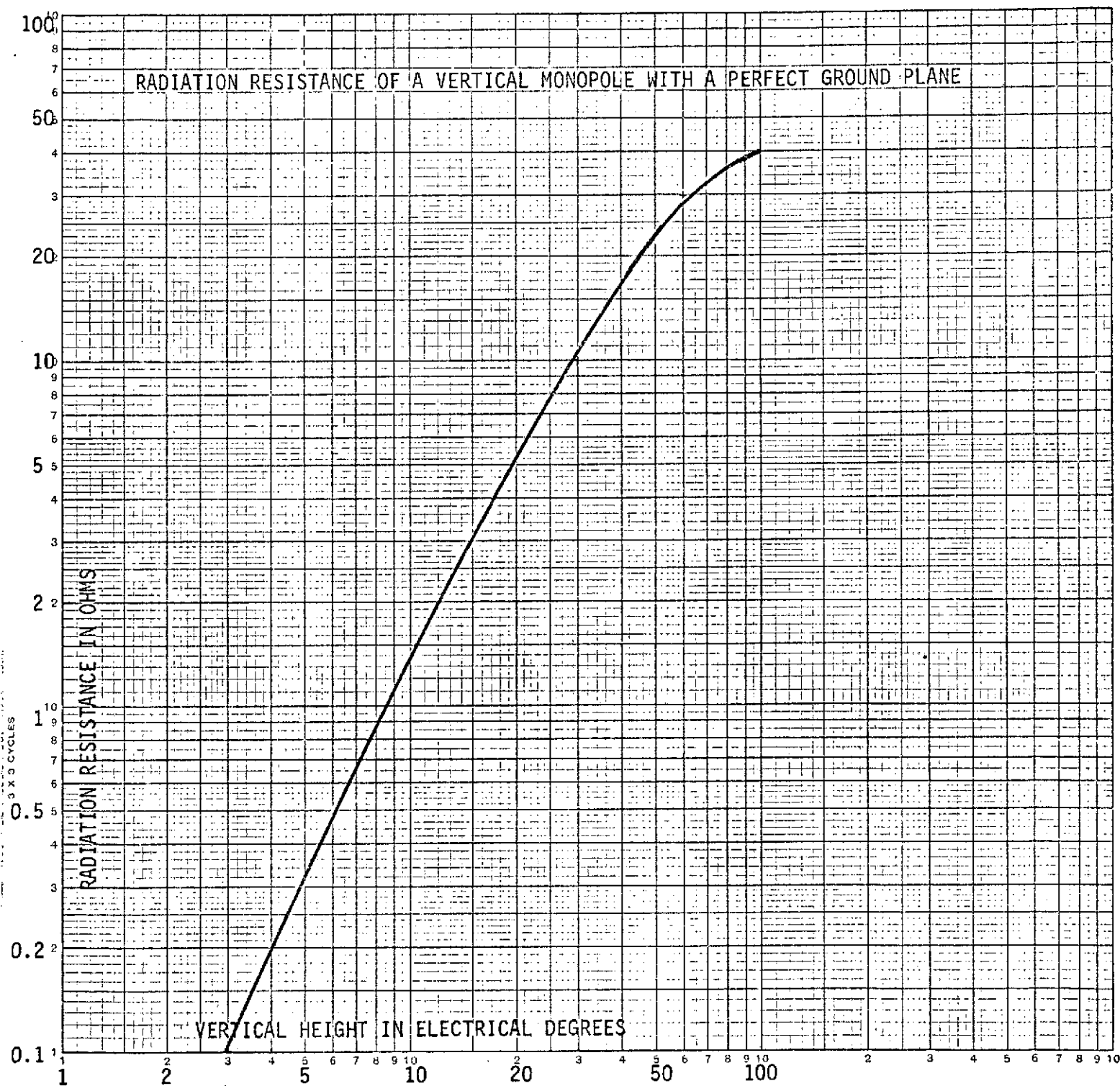
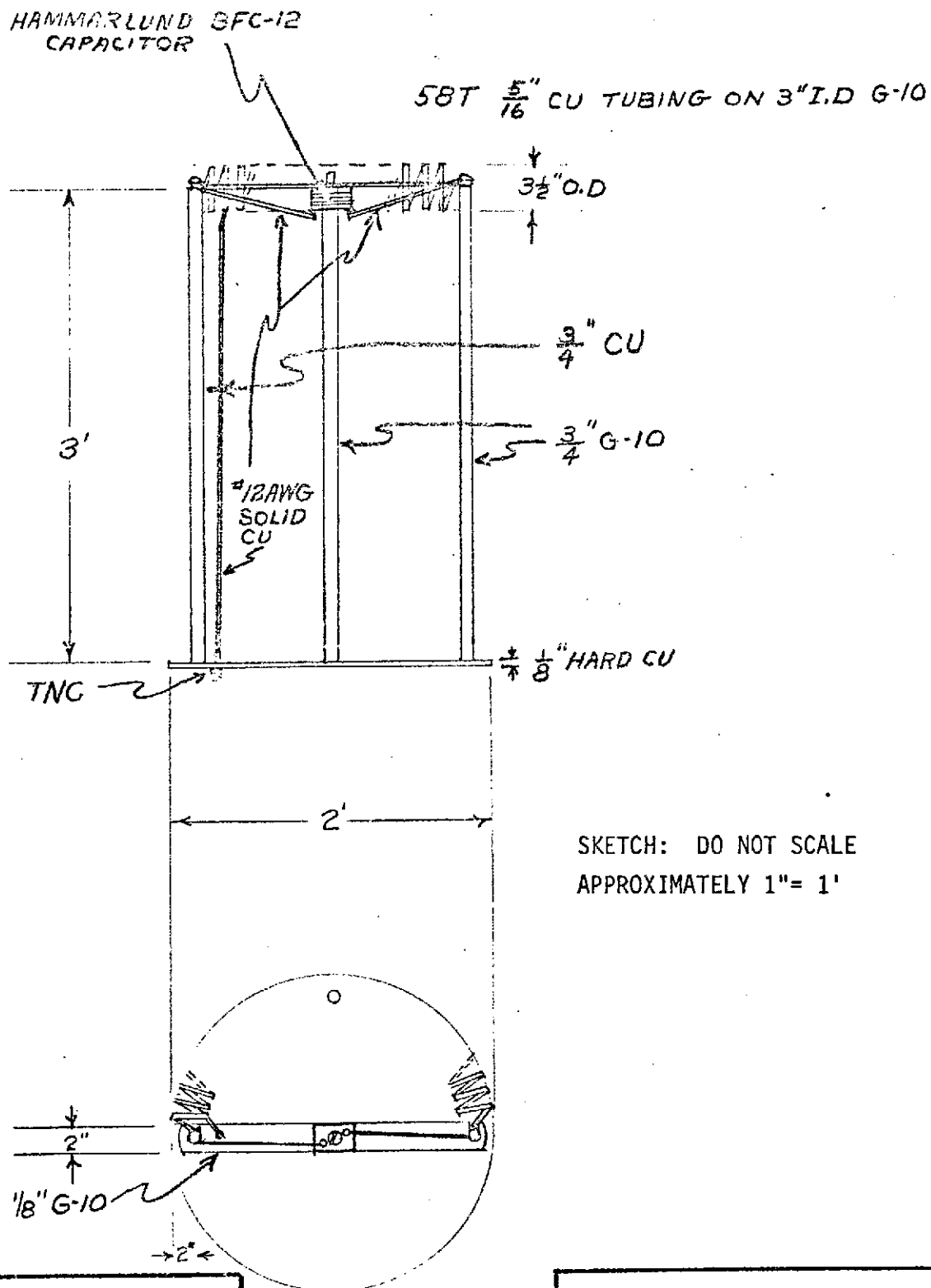


FIGURE 3.

# THREE FOOT TOP HORIZONTAL COIL (THC) TELEMETRY ANTENNA



DESIGNED BY: R.W.FREYMAN

PROTOTYPE ACCEPTED: 6-15-73

FIELD TESTS COMPLETED: 6-29-73

*R. W. Freyman*

SENSORY SYSTEMS LABORATORY

"THC" TELEMETRY ANTENNA FOR  
BUOY-TO-SHORE TELEMETRY SYSTEM

FIGURE 4.

IMPEDANCE COORDINATES—50-OHM CHARACTERISTIC IMPEDANCE



TITLE THREE FOOT TOP HORIZONTAL COIL ANTENNA  
WITH TAP FOR 50 OHM FEEDLINE AT 1 TURN

DATE 6-30-73

IMPEDANCE COORDINATES—50-OHM CHARACTERISTIC IMPEDANCE

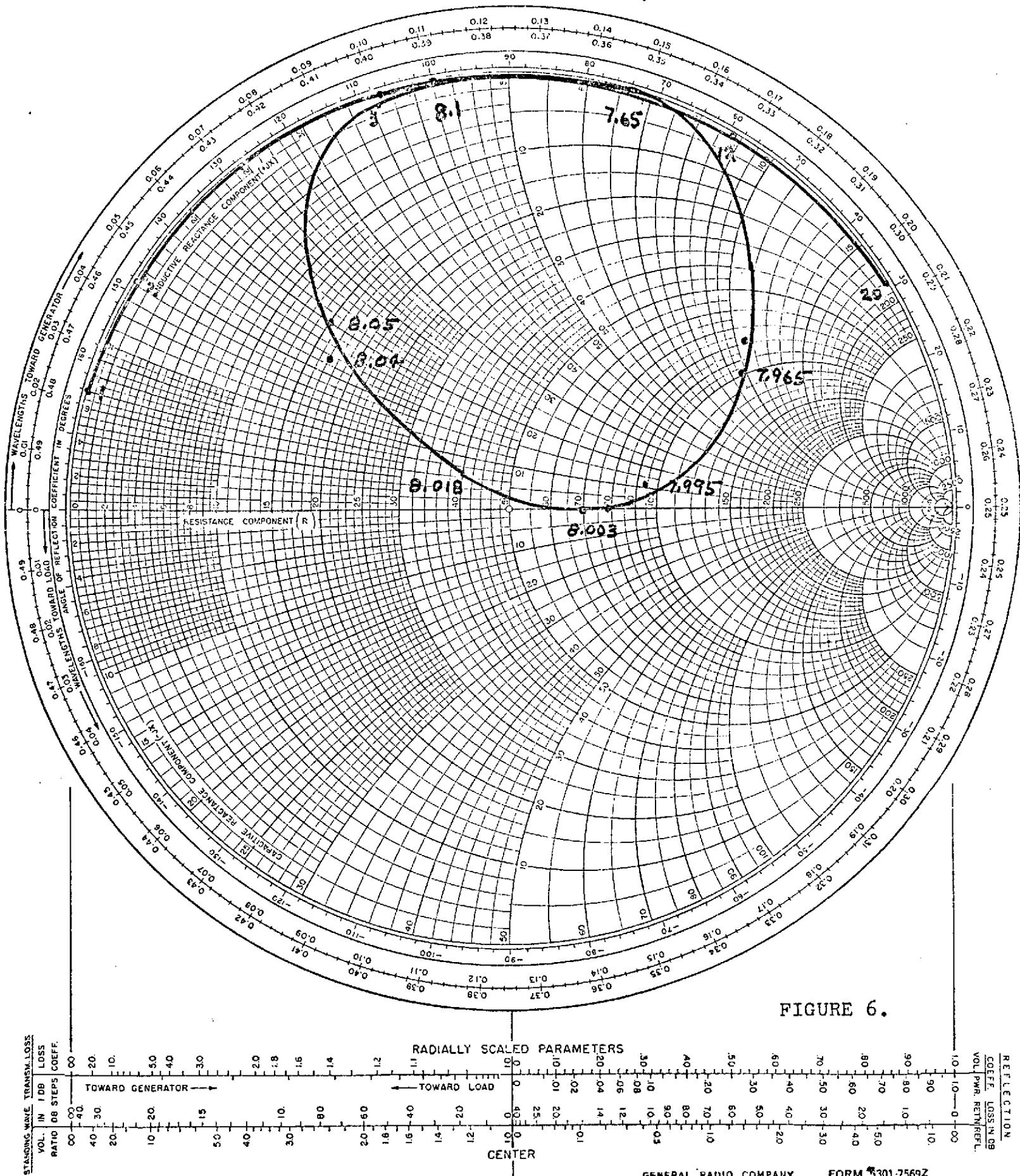


FIGURE 6.

Prototype Approved: *2057 6-24-73*



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